ENVIRONMENTALY GEOTECHNOLOGY OF CLOSURE OF MERCURY IDRIA MINE

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ABSTRACTS

The type and the quantity of closure activities and of rehabilitation measures are adapted to the circumstances and needs of present state of Mercury Mine Idria. The basic principles of preservation of life on the permanent basis, of protection of health of people and animals and of being friendly to the environment are taken into account.

The past five centurias of the Idria Mercury Mine's operations have had consequences on the environment, which have directly influenced the deformations developing in the wider exploration area. In order to guarantee safe and technically progressive ore mining, permanent pumping of mine water and the constant modernization of technology and other working fields, including ore processing and heating, increased ore production, the spread of mine works in to greater depths, and difficult rock conditions have in the past demanded the effective cooperation of different branches of technical and natural sciences. Mine shutdown works, which include grouting and hardening destroyed areas, as well as filling parts of the mine and backfilling empty spaces (i.e. mine roadways), are now in the final stage. The efficiency of mine shutdown works is constantly being verified by means of geotechnical and other measurements and observations, while considering the local rock conditions. The paper present problems of environmentaly geotechnology of Idria Mercury Mine closure works.

Key words: Mercury Mine Idria.

INTRODUCTION

The elaboration of the program for closure of the mine has shown that the closure of the mine will be, technically, very demanding. This results from the very complicated geological structure of the mine in Idrija, from the 500-year excavations and from the town of Idrija being built exactly above the deposit (Figures 2. and 3.).
Despite of the fact that the Idria Mercury mine still had a defined amount of ore reserve, a detailed analysis of the possibilities of further operation has shown, that it is necessary to shut down the mine.

In respect to the fact that, in the span of 500 years of mining, the town of Idria was established and expanded partially above very mine, it has been necessary to carry out the closing of the mine in such a manner, that the town will not be endangered by the expected deformations on the surface. In concern to the geological structure of the Idrija deposit, the lower part of the mine is of solid rock. No special closure works have been foreseen for this part of the mine, except filling of the vertical objects and dismantling the equipment. The sinking of this lower part of the mine is planned. The upper part of the mine is of soft rock, predominantly of black clayey schist. All closure works, backfilling of mine works with cemented backfill, hardening of old dry backfill, filling of the vertical objects and dismantling the equipment have been foreseen for this upper part of the mine.

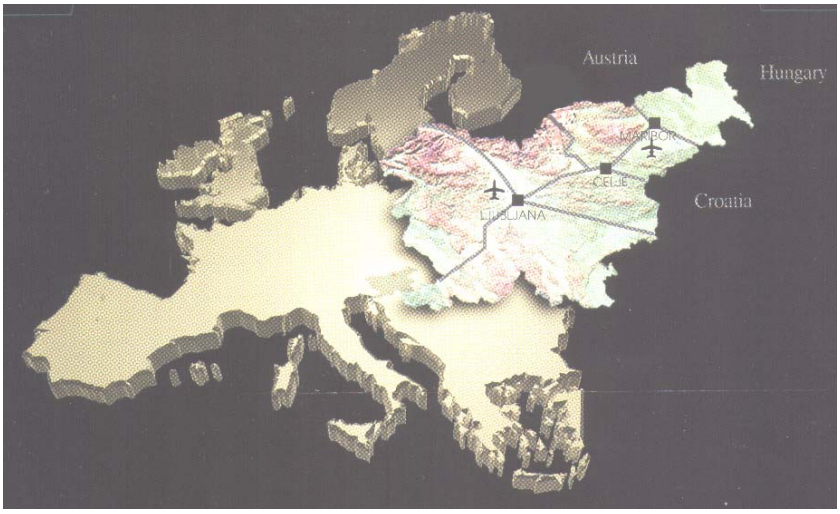

Figure 1.: Layout of the town Idria with Mercury Mine in Slovenia.

IDRIA ORE DEPOSIT

The Idria ore deposit id situated between the center of the town of Idria and the Ljubevsko Valley. It is 1.500 m in length in the longitudinal direction of northwest - southeast. The width of the ore body deposit ranges from 300 to 600 m, and is 450 m deep.
The structure of the ore deposit is extremely complex and is result of extensive sedimental and tectonic occurrences in the Triassic and Tertiary.
In the framework of the orebody's structure we distinguish the lower and upper mine bodies. The lower mine body comprises considerably Permian and Scythian sandstone layers and dolomite layers in normal and subvertical location and the upper carboniferous, anisian and longobardia schist layers, tuff and dolomite layers in complex interrelations.

CLOSING OF THE MINE

Several reasons influenced the abandonment of mercury ore excavation, initially in the 1970's and finally in the late 1980's. On the one side, an intensive international campaign

had been lauched against mercury, whose harmful effects were researched in various fields. Another reason was the very low price of this metal. Several years passed before the state administration adopted a decision on the gradual shutdown of the mine in the long-term abandonment of mercury production. In addition to the above mentioned factors, particular emphasis was laid on the long-term effects of the mine on the sinking surface, i.e. the town of Idria which stands directly above the mining facilities, the potential instability of the natural and artificial slopes above the mine, and the pollution of the environment with the mercury in the town of Idria itself and far downstream along the Idrijca River and Soca River, including the Gulf of Trieste.

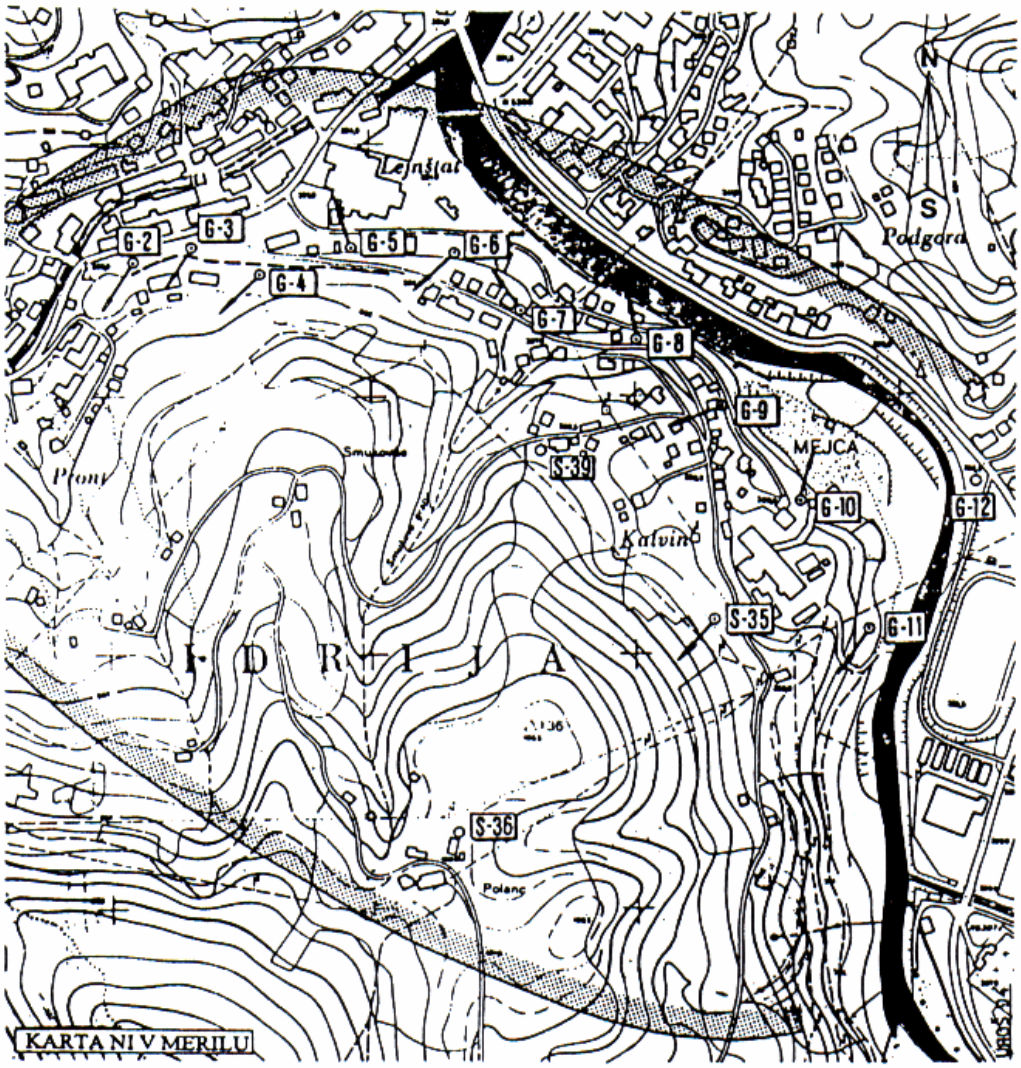

Figure 2.: Surface over the Idria Mine, part of Idria Town.

The main problem of closing the mine is tied to the prevention of the roof layers subsiding and of landslides on the surface caused by this subsidence. Particularly the area where the town of Idria reaches above the mined out areas of the mine. This is particularly important, as for quite some time during the operation of the mine sliding, that is creeping of the

surface has been observed and as a result of this damage has been caused to the buildings in the very town of Idria.

With the detailed analysis of the primary and secondary stress deformational states in the rock masses in the broader area surrounding the subterranean mined out complexes we discovered, that is, discussed the possibilities of using certain types improvement of works in relation to improving the stability conditions on the surface. The rough relief, which on all sides of the basin surrounds the town of Idria, is more level in the southern area, but much more unfavorable in respect to its rock composition and the stability conditions connected with it.

On the basis of investigations, which were chiefly directed in: - geological and engineer-geological investigations, - geomechanical or geotechnical investigations, - geodetic and mining survey measurements, - numerical analyses of the changing of deformational and stress fields with their appertinent stability analyses, we found that the sliding and, in same areas, creeping is the result of combination of influences of the mining and the primary geological structures. The natural conditions of the stability of inclining areas above Idria mine are, in the concerned area, extremely questionable, as the harder rock, wich is cracked and permeable to water, lies on the softer rock with less shear strength.

We anticipated as a sanitation measure in relation with improving the stability conditions also cemented injection measures. With these we wish to improve the strength of irregular and partially already damaged intermediate pillars, which were created as a result of the mining and to establish the close contacts of the backfill with the roof at specifically critical areas.

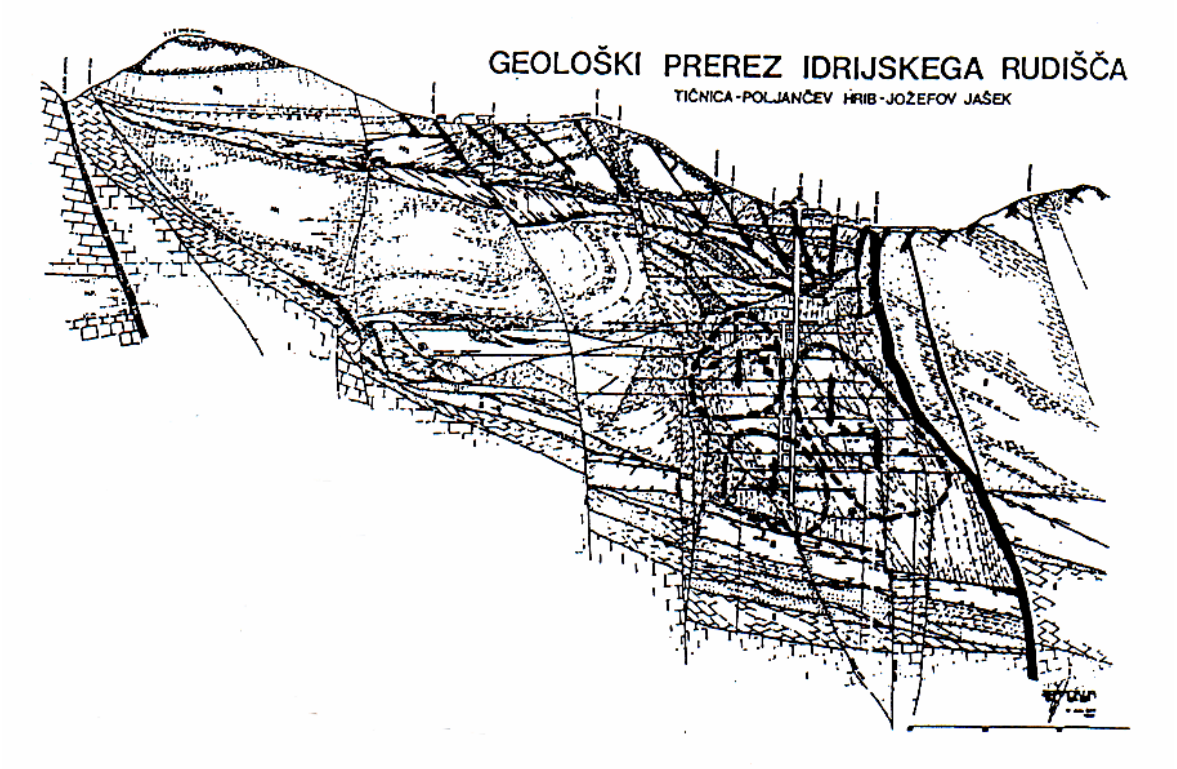

Figure 3.: Geological cross section over the Idrija mercury deposit; Directions of subsidences caused from compressing of backfill.

More extensive closure and rehabilitation works are planned for the upper part of the mine. Its geological structure is more complicated. In addition to that, the main excavations were carried out there. The type and quantity of the work are connected with the mine damage on the surface and the possibility of further spreading those damages. Even though there is some native mercury in the deposit, no special rehabilitation measures concerning the environment pollution with mercury have been planned.

CONSEQUENCES OF MINING ON THE SURFACE

Certain subsidence and sliding of the terrain and minor damages on the buildings above the deposit in Idrija were noticed even when the mine still operated. When the excavation of the ore stopped, thus also without mining activities, the subsidence of the terrain is still in progress. The mechanism of subsidence was not quite understood and cleared when the program was being elaborated. Thus, with the program, the system of suitable measurements and observations was planned with the purpose of clarifying the consequences of the excavations going on for several hundreds of years and the estimation of the danger for further subsidence.

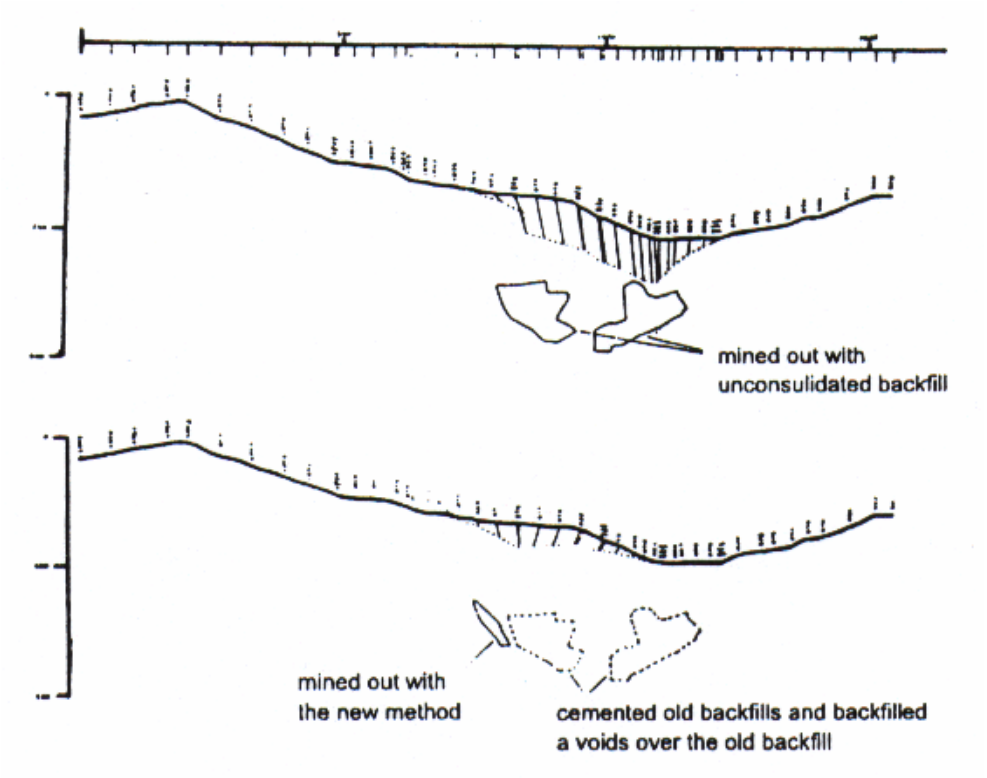

Figure 4.: Calculated vectors of movements:
a) after the normal ore production was stopped,
b) after the sanation works (mined out with the new method and injected works in old mine structure).

It was presumed that the subsidence of the surface resulted from the increasing deformations of the hanging walls, due to the still unfinished compression of back-filling of the mining ore bodies, with subvertical position, which were excavated in the past. Due to the inconvenient configuration of the terrain and the presence of the still active Idrija fault, the subsidence and the sliding of the slope above the deposit in the direction of the riverbed of the Idrijca take place.
Some were of a different opinion: The observed sliding of the surface was not directly connected with prior excavations and the still lasting compressions of back-fills. It was estimated that the slide was caused by the steep position of the slope and connected with the inconvenient hydrogeological circumstances.
Suitable research supported with mathematical modeling proved that the consequences of the shifting of the surface are, above all, connected with the non-compressed back-fills in the mine (Figure 3.). In spite of that, several additional research studies and observations, necessary to prove the reasons for the shifting on the surface, were added into the program.

PLANNED REHABILITATION MEASURES

In the lower part of the mine, in addition to the removal of all the equipment, filling of vertical mine objects with cemented back-fills is planned; cemented back-filling is foreseen for main vertical connections - shafts. All other mine objects are not to be rehabilitated, the stops are not rehabilitated and the lower part of the mine is to be flooted with water.
The upper part of the mine of less solid rock, where the undug space is the biggest, is not be flooted with water. Filling of vertical and horizontal mine structure areas with cemented back-fills in areas above the back-fills are to be filled with cemented back-fills. The purpose of the planned rehabilitation measures is to stop further compressions of the back-fills and thus, of the subsidence of the surface (Figure 4.).
In addition to the above mentioned fortifying works, consolidated excavation works were planned (Figure 5.). With prior analysis on the mathematical model, it was discovered that it is possible to change the direction of the deformation field with partial undigging of certain mining bodies, which results in a decrease of the subsiding slope on which the surface above the mining area subsides (Figure 4.).
Special attention has been devoted in past years to the improvement of reinforcement and backfilling technologies, as most of the vertical and horizontal mine areas below the IVth level have been filled with reinforced backfill (cemented backfill). For the purpose of injection and backfilling of pit areas wich can not be reached with simple backfilling technologies, a special injection station was created on the surface above the mine. The station is used to pump backfilling materials into lower lying mine areas through an open shaft and drill holes.

RESEARCH, MEASUREMENTS AND OBSERVATIONS

The program of closure defines the type and quantity of the research necessary for the final definition of the rehabilitation measures and the measurements and observations for the

control of the success of the carried out rehabilitation measures. The following research studies are defined and their costs estimated:

- geological researches,
- hydrogeological researches,
- geotechnical researches,
- surveying and geodetic observations.

Geodetic measurements on the surface

Geodetic measurements were begun in the middle of the 20th century, while extensive geometric observations, aimed at monitoring the stabilization of the mine, were not performed until 1990. Measurements were also performed on important infrastructural buildings and facilities, too. Before the commencement of shutdown works, the horizontal and vertical movements of terrain above the mine were up to 25 mm/year and up to 14 mm/year, respectively.

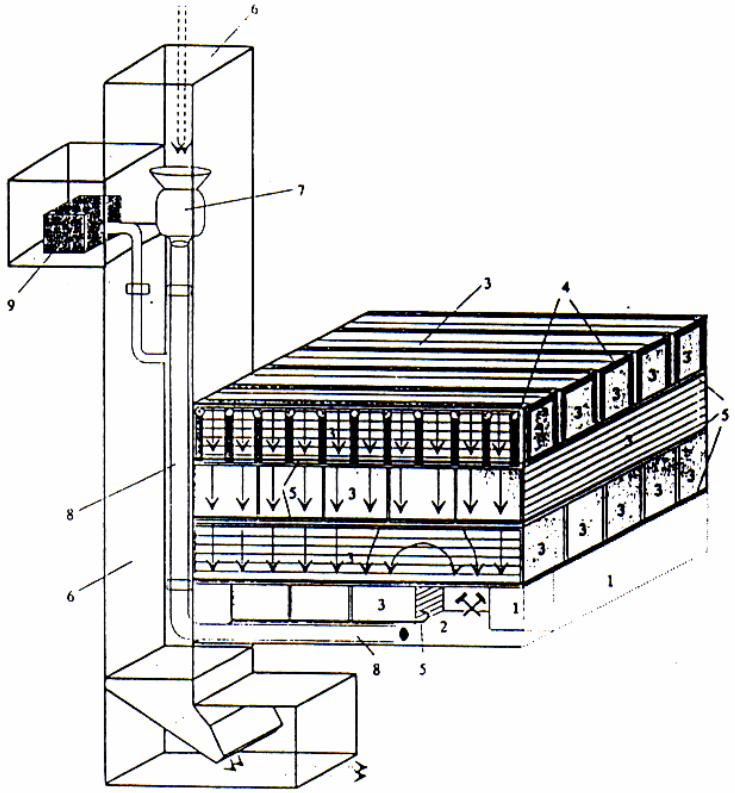

Figure 5.: New mining method; underhand cut and fill stopping method with cemented backfill.

-----> Stowing material
·····> Ore
1. Ore
2. Slope in advance
3. Cemented backfill
4. Timber sets
5. Still reinforcing
6. Chut
7. Blowing machine
8. Blowing tube
9. Cement milk mixer

Displacement measurements in the mine

The wide mine surveying mesh included measuring points placed on different mine levels connected to main points near the mine shafts "Delo" and "Borba". Each measuring point is stabilized on the bottom or in the roof of mine roadways to allow the measurement of vertical movements and, in some cases, horizontal movements as well. Each measuring cycle was performed twice per year if any extreme displacements occurred as the result of closure works during flooding of the deepest part of the mine. A trend of vertical displacement similar to that on the surface was also found in the mine. The measurements performed on levels I. to XI. showed a displacement syncline near the Inzaghi shaft, where a maximum subsidence was found. The measured movements change a little from year to year and, in the past year, horizontal movements declined to an average 8 mm and vertical displacements to 4 mm.

Measurements of horizontal displacement in vertical inclinometers

Measurements of inclinometric boreholes have been conducted since 1989. The boreholes are located in areas with the most intensive shifts. In the period from 1989 to 1996, 17 inclinometric borehols were activated. In that year the horizontal shifts, measured twice a year, attained values of up to 21 mm/year and vertical shifts up to 10 mm/year. Measurements of inclinometric borehole deformations have shown that the shifting of terrain above the pit is continuing, but with a decreasing tendency, which is undoubtedly the consequence of abandonment of excavation works and the conduction of reinforced backfill works in the pit. In the last years (2001-2006), we have measured some local increasing deformatins in area with geotechnical unstable rocks (Carboniferous shale), but this, we consider, are still in the process of stabilizing and do not present any major hazard.
The results of several years of measurements and observations have shown that not only different slides are forming above the pit, but a large sinking crater is also forming with its centre around the Inzaghi shaft, where most of excavation works took place.

Measurements of stress changes using measurement cells

In addition of other measurements and observations, probes were initially incorporated at various locations to monitor stress deformation chnges in rocks and backfillis during shutdown works and partial flooding with water of the mine. The measurements of secondary stress deformation changes at the XIV^{th} and XV^{th} levels and measurements of secondary stress states on the IV^{th}, VI^{th} and VII^{th} levels have served to illuminate the deformation processes in progress. Our principal intention, however, was to determine the impacts of flooding of part of the pit on the rock structure of the mine.
It is highly probably that the changes found by measurements of secondary stress deformation changes at the XIV^{th} and XV^{th} levels are linked to the sinking of areas above mine exctraction works and the effects of time-dependant occurrences around the Idria fault. The results of measurements of secondary stress states on the IV^{th}, VI^{th} and VII^{th}

levels shown that the time-dependent changes occurring in the past year, are considerably more extensive than in approximately the same time intervals in previous years. The substantially increased stress in cells on the IVth and VIIth levels is explained by the fact that the rigidity of old reinforced backfills in the broader areas is incomparably higher than in other backfills, which were not additionally injected or grouted.

RESULTS OF THE RESEARCH, MEASUREMENTS AND OBSERVATIONS

The researches, measurements and observations carried out so far have confirmed the assumption that the subsidence and sliding of the surface above the Idrija deposit results from the non-consolidated back-fills of numerous stops. Therefore, the stability of the surface of the deposit can be achieved, above all, with carrying out the rehabilitation measures in the mine and not on the surface (Figure 4.).
Although the success of reinforcement and backfilling works cannot be evaluated at present, a number of indicators point to the adequacy of planned and executed procedures.
It cannot be denied that five centuries of the mine's operation below the town of Idria have caused various changes in the mine, rock structure in the vicinity of the mine, and on the surface. Although mining works were continuously accompanied by backfilling of dug out areas during the mine's entire operation, the backfills were so demaged that they were unable to prevent the sinking of the surface, and their rheological characteristics were not such as to reduce sinking without additional reinforcement measures.
Frequent visual inspections of various facilities on the surface have shown that the intensity of time-dependant shifts is gradually decreasing, and that damage in the form of faults and shear shifts has also decreased considerably. In same cases when cracks were more open in a specific period, but closed after a number of years. It may therefore be concluded that the sinking of the surface was not uniform and that reinforcement measures indirectly influenced the gradual reduction of damage on the surface.

PROGNOSIS OF THE DEVELOPMENT OF DEFORMATION PROCESSES IN THE LONG TERM

The estimation of time-dependant deformations on the surface above the mine has allowed to prepare a prognosis of the development of the deformation field in the next ten or twenty years. According to the simple logarithmic approximation, the sinking of ground in a specific area can be expected to continue for at least 10 years, and therefore the set deformation reduction rate criterion of 1 cm/year will be attained after this period.
On the basis of systematic surveying and geodetic observations, the analysis of the measured deformations in bores and geotechnical analysis, it was established that a typical crater was being formed above the deposit (Figure 3.). This requires intensive and consistent filling of all open mine structures and the consolidation of the old ones which have not yet been compressed. In such a way the present compression of the old backfills will stop and the whole mine structure will be stabilized.

CONCLUSIONS

The exploitation of new big energetic and mineral deposits out of Europe has increased the supply of those raw material immensely - at keen prices. Gaining raw materials in smaller, partly already used deposits in densely populated Europe is impossible also because people are aware of ecological problems. Even mines which were very successful a few decades ago have to stop gaining ore because of economical and ecological reasons. Closure of mines have to be thought over and, above all, environmentally friendly. Parallel with closure activities the purpose of which is to prevent the possible harm which could be done after the cessation of the mining activity, rehabilitation works which should abolish the consequences of the long-term mining harmful to the environment are, to be planned.

Therefore, the closure of mines, is technically very demanding and expensive procedure nowadays. As a rule, individual companies exploiting a certain deposit, should solve and abolish harmful effects of mining on the environment when they still operate, or they should secure financial means for the closure and rehabilitation activities after the cessation of mining. Mercury mine Idria, which is being closed down have operated for several hundreds of years. The mine owners changed and eventually, the state became the owner of the mine. Upon the decision concerning a total and permanent cessation of gaining a mercury ore, a law is passed by the state which ensures an environmentally friendly closure and the necessary financial means.

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